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Geothermal plant project phases and decision gates

Pre-workshop course ITB

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Stakeholder game - summary

- Reduction of risks
  - *What is acceptable?*

- Important role for the government
  - Government funding or tax incentives, *unfortunately limited resources*
  - Guarantee letter
  - Tariffs → Power purchase agreements
  - Clear regulatory framework
  - Transparent process
- Share risk → both government and GT developer have the drive for successful development

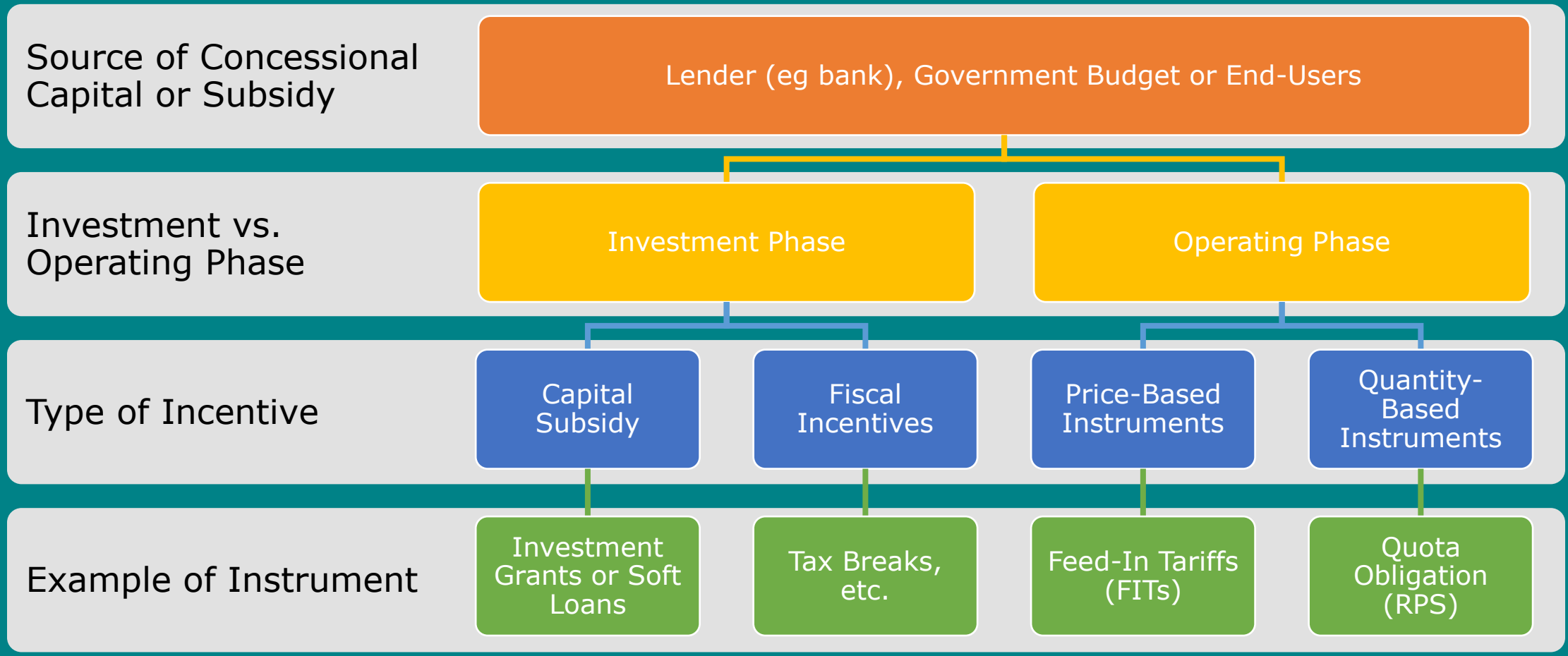
- Public acceptance/ lack of understanding
  - Education (both government as locals)
  - Community benefits (eg jobs)

Stakeholder - Government

Reliability, affordability and sustainability of energy supply
→ Stimulate the development of geothermal energy plants

- Policy & planning
  - Set long-term targets for (geothermal) electricity and heat.
  - Introduce economic incentive schemes for both electricity and heat until geothermal has reached full competitiveness.
  - Support reducing financial risks involved in geothermal exploration.
  - Introduce streamlined and time-effective permit procedures for geothermal development.
- Supervise & monitoring
  - Licensing & permits
  - Supervise on safety, health & environment
- Implement publicly accessible geothermal resources databases.
  - Implement publicly accessible geothermal resources databases
  - Enhance training, education and awareness for skilled workforce.
- Stimulate knowledge development
  - Increase public R&D funding, ensure sustained R&D funding in the long term.
  - Expand international R&D collaboration, making best use of national competencies.

Regulatory instruments to support the deployment of renewable electricity



Adjusted from ESMAP – Geothermal handbook; planning and financing power generation (2012)

Stakeholders – Industry

Geothermal developer

- The geothermal developer is the initiator of the geothermal project. Often the developer contracts a EPC (engineering, procurement and construction) contractor for the detailed engineering and the field development.
- The operator is the user of the geothermal plant during production.

Financer (e.g. bank)

- Lends money to the geothermal developer as investment

Contracters

- Manufacturers of components
- Drilling companies
  - Develop cheaper drilling technologies and new drilling methods that decrease costs.
  - Improve downhole instrumentation and well monitoring and logging.

Power sector

- Perusahaan Listrik Negara (PLN) is the state-owned company responsible electricity distribution.

Municipality – local people

- Dislike changes that might affect water supply, cause air pollution, are noisy, ugly or change nature/environment

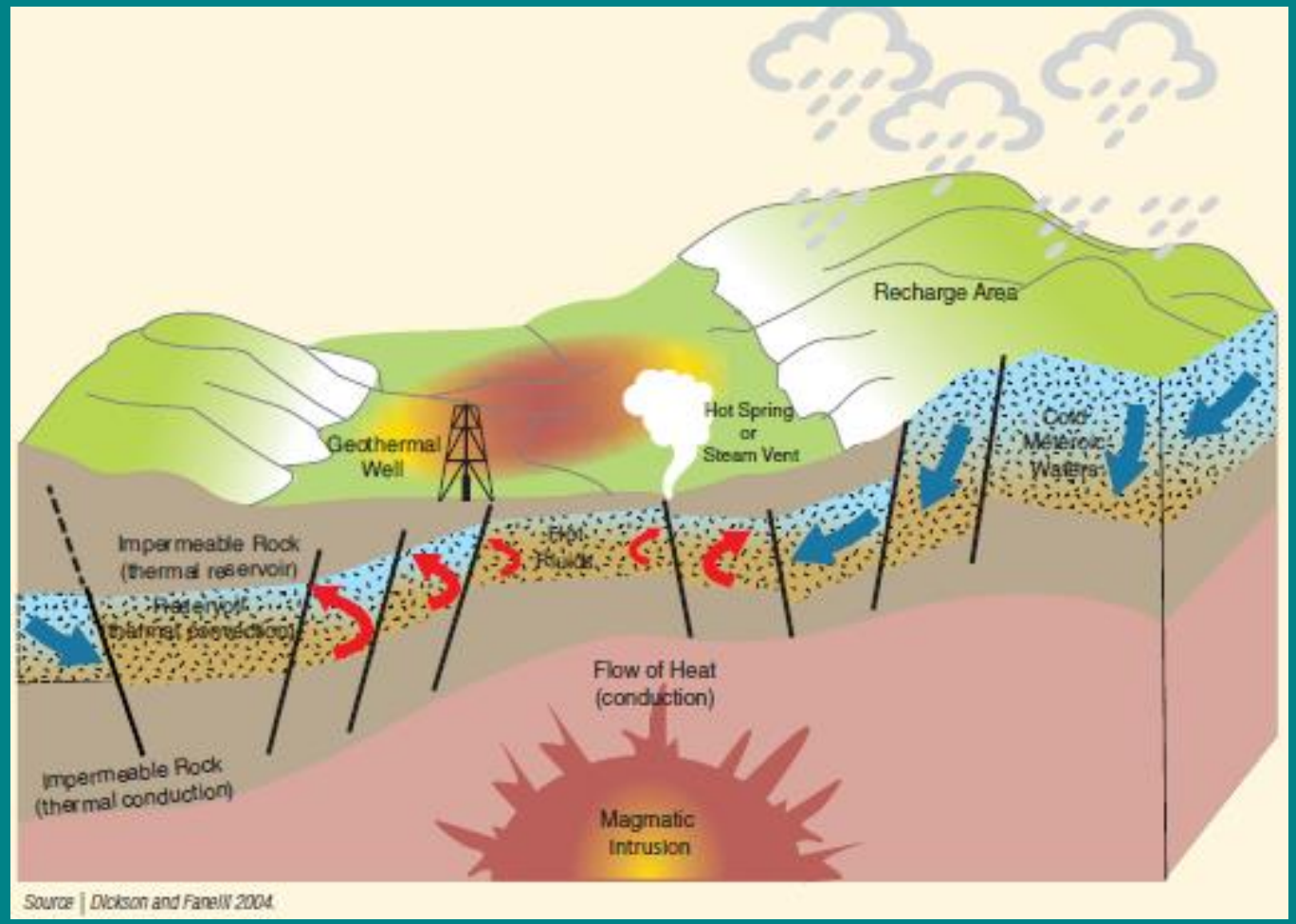
Successful geothermal development

Key Elements:

- Availability of sufficiently accurate geothermal resource data and other relevant information
- Transparent & supportive policies and regulations
- Access to suitable financing for the project developer

Geothermal energy

- Geothermal System All parts of the hydrological system involved, including the recharge zone, all subsurface parts, and the outflow of the system.
- Geothermal Field is a geographical definition, usually indicating an area of geothermal activity at the Earth's surface. In cases without surface activity, this term may be used to indicate the area at the surface corresponding to the geothermal reservoir below.
- Geothermal Reservoir indicates the hot and permeable part of a geothermal system that may be directly exploited. For a geothermal reservoir to be exploitable, it needs to have sufficient natural heat that transforms to pressure and brings the steam to the surface.
- The Geothermal Reserve is the commercial exploitable geothermal energy.



Differences between oil & geothermal

1 | Economy/Markets |

Oil is an internationally traded product, easy to store, transport, and sell.

Geothermal steam cannot be sold or priced outside of the local heating and electricity markets. Introduces off-take risk because of limited options for selling the product. Integration of geothermal projects into the local grid requires additional infrastructure, permits, and contracts.

2 | Geology |

Drilling for hydrocarbons is often carried out at greater depths than geothermal drilling

Oil fields are generally in geologically stable environments and can be more easily confirmed by surface exploration technologies.

Geothermal fields are often in volcanic and fractured zones and their potential must be confirmed by drilling.

3 | Fluid or Steam Composition |

Even if a geothermal reservoir is proven to exist, fluid and steam may, in some cases, have a chemical composition that precludes their use for power generation

it is usually possible to find ways to process and use oil even if its chemical composition is problematic.

4 | Reservoir Depletion |

Oil can be pumped until the economics of production fall below a set threshold, or, in the best case, until the reservoir is considered depleted.

Geothermal fluids have to be reinjected to avoid pressure drops. Therefore, groundwater flows and reservoir refill systems have to be understood to avoid depletion of a geothermal

Geothermal energy plant

Geothermal Power

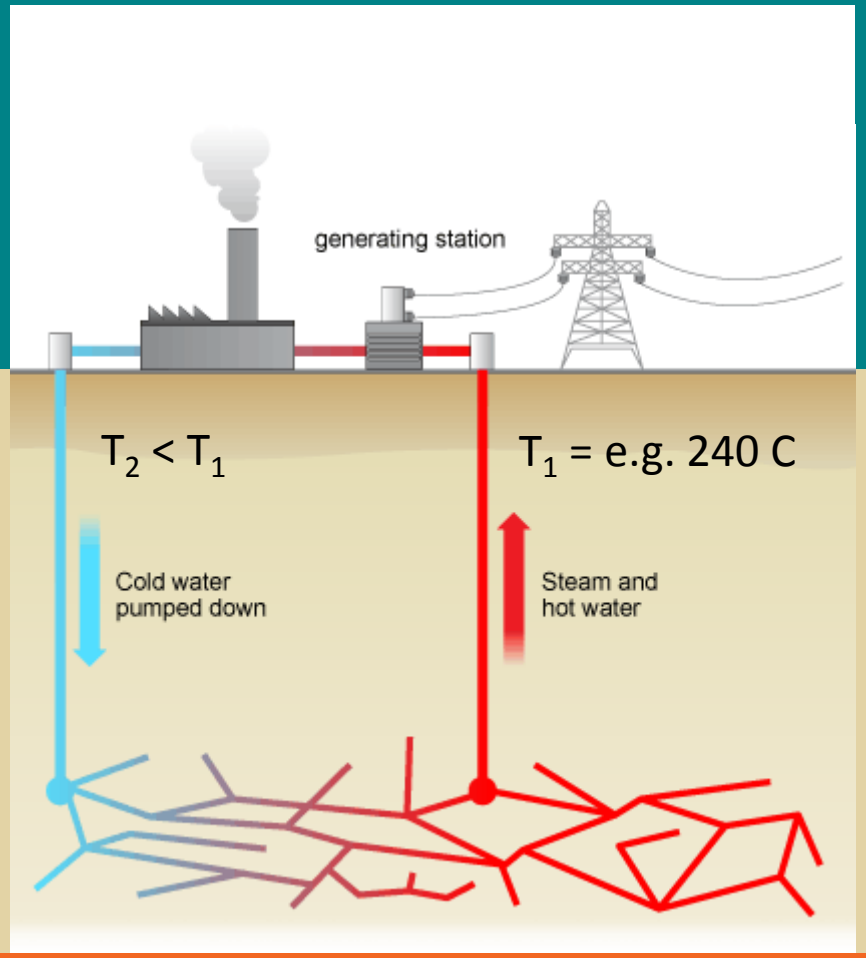
Heat capacity fluid

$$Q = m * c * \Delta T$$

flow

$T_1 - T_2$

Flow & temperature is dependent on subsurface geothermal system and the technologies used



Energy production:
- power market (PPA)
- heat demand

Energy source:
- field capacity

Geothermal energy plant

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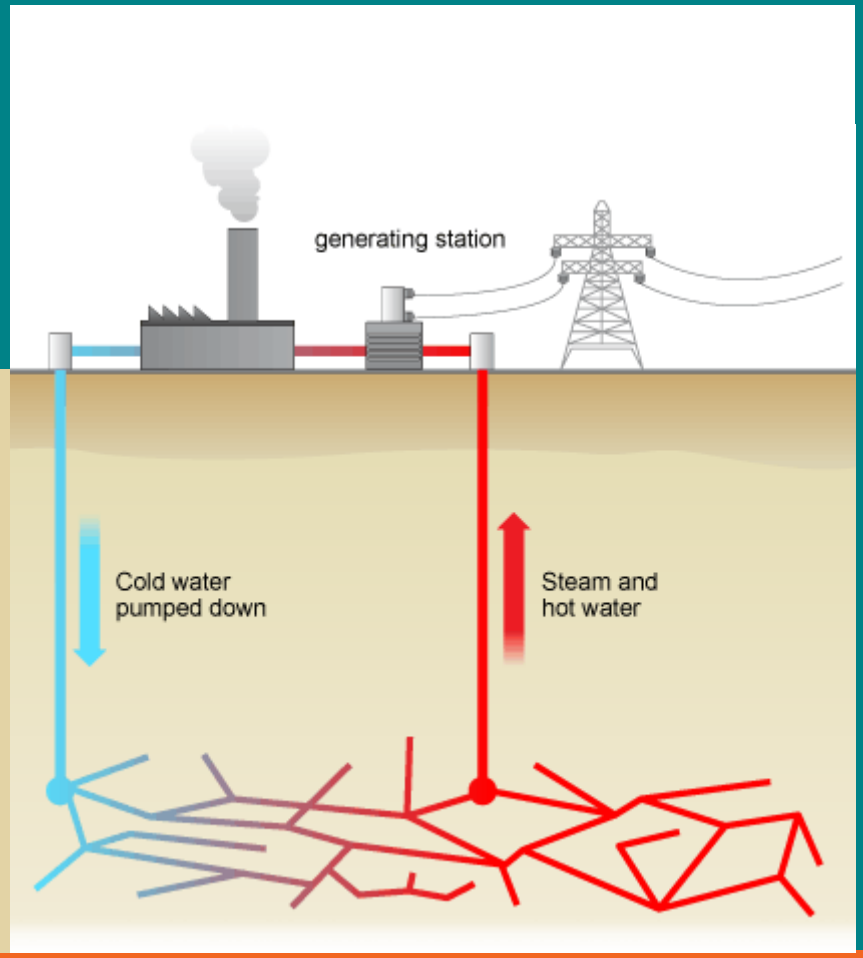

Energy source:
- field capacity

Technical aspects:

Design geothermal energy plant

Financial aspects:

Business case, bankability

Environmental aspects:

Health, safety, social

Geothermal energy plant

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Design geothermal energy plant

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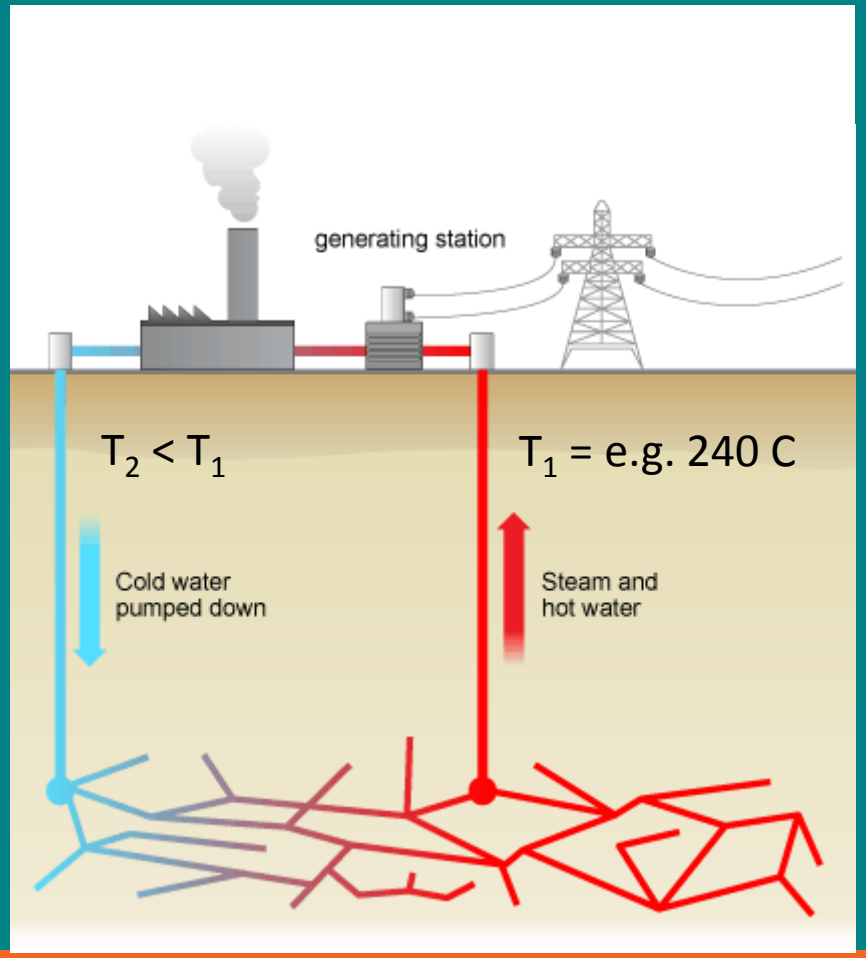
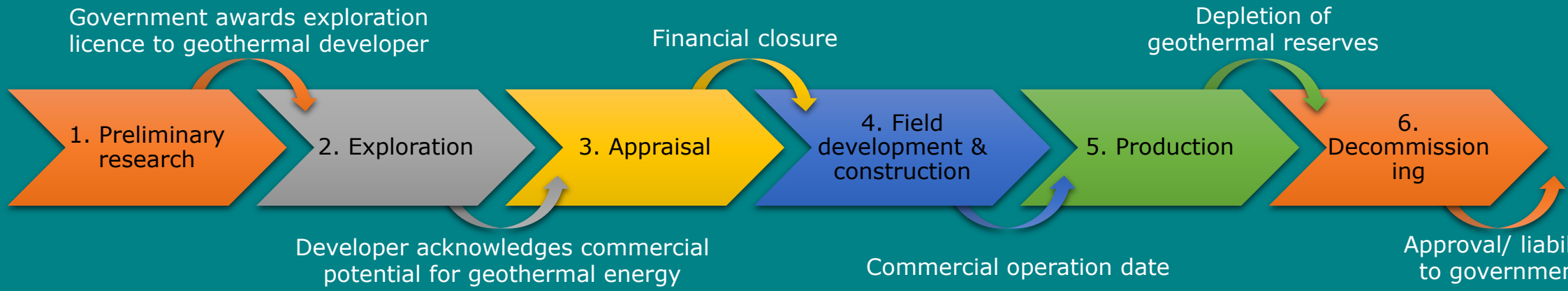


- Costs of investments are very high
- Large uncertainty of the size and location of the geothermal reserves

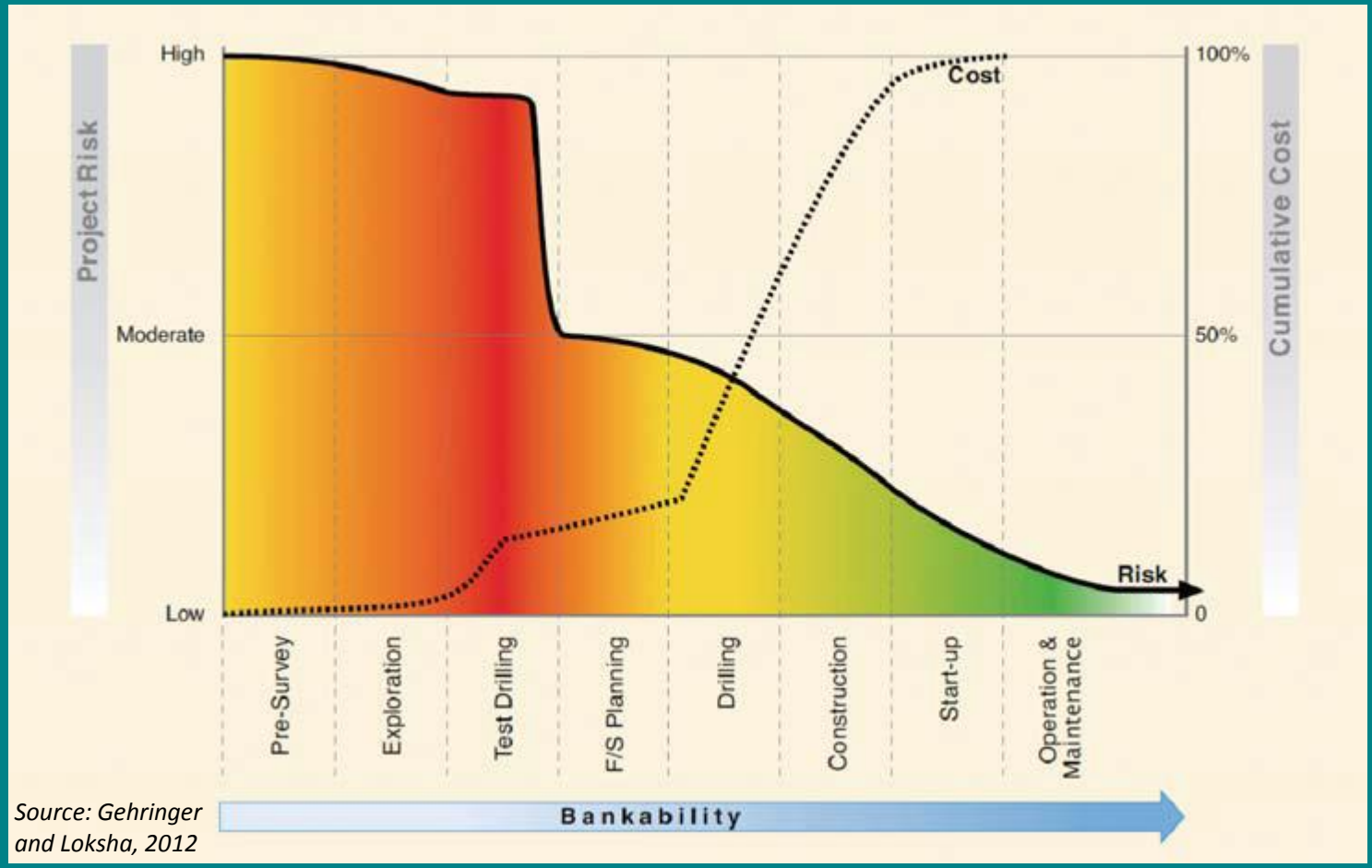
➢ Step by step development, while balancing the investment costs and risks

Geothermal energy plant - Development phases



1. Preliminary research – Collect & analyze data to predict location as well as existence of geothermal resources.
2. Exploration – Surface and subsurface exploration (incl shallow drilling) to prove the geothermal resources.
3. Appraisal – Test/ confirmation drilling; typically 3 to 5 full size wells to confirm the existence, exact location, and commercial potential of the reservoir. Project review and planning – Technical, economical and environmental feasibility of a proposed business plan and plan for development and operation.
4. Field development & construction – EPC contracting: Detailed design, drilling of the production wells, construction of the power plant.
5. Production – Direct and indirect utilization of geothermal energy. Operation and Maintenance of the geothermal energy plant.
6. Decommissioning – Well abandoning

Problem geothermal energy plant



Source: Gehringer and Loksha, 2012

- Investment costs are high & high development risks: only 70-80 % of drillings are successful
- Life-cycle phases: decrease development risks (by resolve uncertainties)

Pre-phase: Reconnaisance

First reconnaissance of a geothermal area: Collect & analyse data to show the existence of geothermal resources.

- Siting study: identify potential geothermal sites
- Gather all existing literature data and perform airborne survey (collect maps)
- Gather information on possible market (connections) for energy and heat

Pre-phase: Reconnaisance

Decision/ action by the government	**Required information/ knowledge by government**
Prioritize open GT-acreage	Regional information on geology, and experience with nearby GT-fields
Publish license bidding round	Terms and conditions that will apply to new GT field operators, description of geology and market.
Evaluate license bids by developer	Operator submissions, including PDO (Plan for Development and Operation)
Prioritize license bids by developer	Govt policy for which KPIs are (more) important than others. Understanding of how these KPIs have been established by the operator and how to interpret them. Understanding the risks in the forecast Government Take.
Select developer and start further negotiations	Establish details of license agreement
Conclude (or not) final T&C of concession + issue GT production license	Assess impact of detailed T&C on Govt Take and on govt GT-policy
Monitor developer's execution of PDO	Data & info from field as supplied by operator, fiscalized volumes as obtained from other authorities (tax, regulator, etc.)
Influence developer's updating of PDO as new info is being revealed in time.	Info & know-how on operations, on cashflows and on impact on general GT policy

Pre-phase: Reconnaisance

Open tender round

- In all cases the data generated, both raw and interpreted, must be provided to the Government
- All data regarding a geothermal resource belongs to the Government, because the resource itself belongs to the Government
- However, the current state of national geothermal data is limited, and this increases the perception (and probably the reality) of resource risk
  - Not all data has in fact been provided to the central government

Pre-phase: Reconnaisance

Criteria selection and comparison

- Technical parameters: energy content
- Financial: bankability (mitigation measures)
- Environmental management plan
- Competence company: knowledge & experience
- Company structure: effective organization

Pre-phase: Reconnaisance

Tender document for working area

- Technical details, such as power and energy capacity of the GT plant
  - Installed MW & timing
  - Expected GWh per year produced
- Planning
  - Plan for development & operation (PDO)
- Safety, Environmental and Social aspects
  - Reliability
  - HSE & SR impact analysis of PDO
- Financial aspects
  - Yearly expected cash flow from Govt Take (probably tax mainly) + uncertainty
  - Financial risks – how sure is financing?
- Information / knowledge obtained as a result of the project which may help
  - future projects meeting the companies' hurdle rates
  - the government to negotiate better T&C of new projects
- Regulations:
  - domestic and international standards
  - depth review of geothermal legislation, including laws and regulations on independent power producers

1. Preliminary research

Collect & analyze data to predict location as well as existence of geothermal resources and the potential of a geothermal power plant.

- Visit geothermal site
- Country's power market (demand and supply, potential off-takers and customers)
- Transmission and distribution system, availability of basic infrastructure (roads, fresh water supply, communication, etc.)
- Environmental and social issues: Environmental impact assessment
- Planning of exploration

Goal: *Explore the likelihood of the existence of a commercial geothermal reservoir and to get a first estimate of its exploitable potential*

End of phase: *Government awards concession rights/ exploration licence to geothermal energy company*

1. Preliminary research

Geothermal developer decides to bid for the tender on the information collected for the preliminary report, which is a detailed desk study on the working area:

- Broad overview of the existing data:
  - First estimate on the possible type and size of the reservoir,
  - Country's power market (demand and supply, potential off-takers and customers)
  - Transmission and distribution system, availability of basic infrastructure (roads, fresh water supply, communication
  - Overview of institutional & (local) regulatory frameworks
- Evaluation of the results
  - Environmental impact assessment
  - Recommendations for exploration
- Outlook
  - Exploration planning
  - Financial plan

2. Exploration

Surface and subsurface exploration (incl shallow drilling) to prove the geothermal resources.

- Surface exploration (geochemical, geological and geophysical)
- Drilling of 1 to 3 (relatively shallow) wells to confirm the presence of geothermal resource
- Calibrate the conceptual model (data obtained contributes to knowledge of GT system)
- At least one productive well confirms the existence and samples production fluid to confirm the system enthalpy and chemistry.

Goal: *Update and evaluation of the geothermal field capacity (at least one productive well) Basic process design & financial overview*

End of phase: *Developer acknowledges commercial potential for geothermal energy*

2. Exploration *Surface exploration methods*

Geologic survey - *detecting and characterizing geological characteristics*

- Geological mapping
- Structural mapping
- Dating
- Volcanic hazard evaluation/ earthquake locations
- Slope stability evaluation

Geochemical survey - *chemical analysis*)

- Collection of samples of geothermal steam and water
- Analytical services
- Diffuse soil degassing surveys
- Stratigraphic mapping

Hydrologic survey - *estimate of the volume of fluid in the formation and the rates of throughput*

- Hydrogeological studies and chemical surveys of natural surface waters in geothermal fields
- Flow rate & temperature of fluids
- pH electical conductivity

Geophysical survey - *temperature, conductivity, resistivity*

- TEM-MT measurements, processing and interpretation.
- Seismic surveys, processing and interpretation.
- Seismic monitoring.
- Monitoring of seismic activity shows fracture zones at depth.
- Gravimetric measurements.
- Gravity surveys may reveal tectonic features in the reservoir.

2. Exploration

Well drilling

- Temperature Gradient Holes: drilled to measure the increase in temperature with depth
  - shallow and slim boreholes: less than 6 inches in diameter
  - usually less than 500 meters deep
  - Also allow to collect additional samples of fluids for chemical analysis
- Full size wells
  - typically 8 inches diameter
  - typically few kilometers in depth
  - in stages: continuously check if measurements confirm reservoir model → adjust
  - If full size well corresponds to expectation: production/ reinjection well

2. Exploration

Pre-feasibility study, includes workplan

- Summary of the collected data
- Evaluation of the field capacity with reservoir model:
  - including estimate of possible reservoir temperature
  - flow of geothermal fluid
  - chemical composition of the fluid
- Prepare, design, site and finance of the exploration wells
  - Basic process design
  - Preliminary cost estimate
  - Recommendations for next step (financing/ EIA/ licences)

GO/ NOGO decision: Decide whether to proceed with geothermal development

3a. Appraisal

Test/ confirmation drilling; typically 3 to 5 full size wells to confirm the existence, exact location, and commercial potential of the reservoir

- Drilling programme to set target for existence, location and potention
- Drilling of full size wells
- Well testing & simulation
- Development of reservoir model
- Confirmation drilling: drill number of production wells in order to prove the geothermal reservoir (and presence of sufficient steam)

Goal: *Update and evaluation of the geothermal field capacity (at least one productive well)*

End of phase: *Company decides to prepare application for exploitation licence*

3a. Appraisal

Practical organization

1. Setup a local office for project manager and related staff
2. Ensure cooperation with local authorities and establish communication channels with local communities
3. Setup a steering committee with engineers, scientists and project manager that will deal with drilling problems and what to drill next
4. Secure qualified supervisors and drilling engineers

3a. Appraisal

Design test programme → confirmation drilling → comparison

During test/ confirmation drilling, continuously faced by three choices:

- go ahead with production drilling & risk project failure
- undertake test drilling at a known cost but potentially reduce the risk of project failure through the knowledge gained → decide on next location
- decide that the prospect is not sufficiently attractive to make it worthwhile risking money even for testing

Interference tests between boreholes: how are the wells interconnected

→ Revise & update reservoir model

3b. Project review and planning (Feasibility study)

Determine the technical, economical and environmental feasibility of a proposed business plan and/or activities: Plan for Development & Operation

- Economical feasibility/ business plan: Field capacity, demand analysis (heat & electricity)
- Conceptual design: Design of production- and reinjection wells, transmission access plan
- Drilling plan
- Environmental and social impact study
- Approach financiers with PPA and feasibility study
- License/ permit for exploitation

Goal: *Determine the most economically advantageous project size and the necessary investments*

End of phase: *Financial close*

4. Field development and construction

Drilling of the production wells, construction of the power plant

- EPC contracting - Detailed design
- Construction of the well and production plant
- Connection to electricity grid/ heat network (surrounding infrastructure)
- Test correct installation, proper manufacturing
- Testing & commissioning
- Check shut-down procedures/ Health & safety (Risk assessment documents)
- Training of personnel: Work instruction (safety), manuals, logbooks, work procedures

Goal: *Development wells and construction of the power plant*

End of phase: *Commercial operation date*

Supervision of EPC contractor

- Supervision of detailed design
- Tender documents for civil constructions
- Supervision of the production & reinjection wells
- Supervision of construction of the power plan

→ Delays are very expensive

Agreements in contracts about performance, delivery and installation of equipment

Connection of the plant to the national grid

4. Testing, training & commissioning,

- Resolving many technical and contractual issues with the supplier of the plant
- Commissioning: performance condition tests
- Power plant engineering and construction company (usually EPC contractor) gets its performance guarantees returned as soon as the plant passes the minimum performance conditions as defined in the (EPC) contract
- Recruit staff power plant & training staff
- Optimization: fine tuning the efficiency of the power plant and all other equipment, including the pressures from the wells
- Check documentation
  - RI&E evaluation/ risk assessment documents
  - Hardware & software manuals (work instructions/ work procedures)
  - Technical specifications/ wiring diagrams etc

5. Production

Direct and indirect utilization of geothermal energy. Operation and Maintenance of the geothermal energy plant.

- Selling electricity (to the grid or other off-taker), usually via Power Purchase Agreement (PPA)
- Operation: check performance parameters and verify correct operation status
- Repair workings under maintenance contracts
- Additional drilling (replacement drilling), in order to compensate for drawdown of the reservoir
- Calibration and revision of the reservoir engineering model

Goal: *Ensure a high availability and capacity factor, and ensure steady steam production from the geothermal wells*

End of phase: *Depletion of geothermal reserves*

6. Decommissioning

Well abandoning, clean up geothermal working area

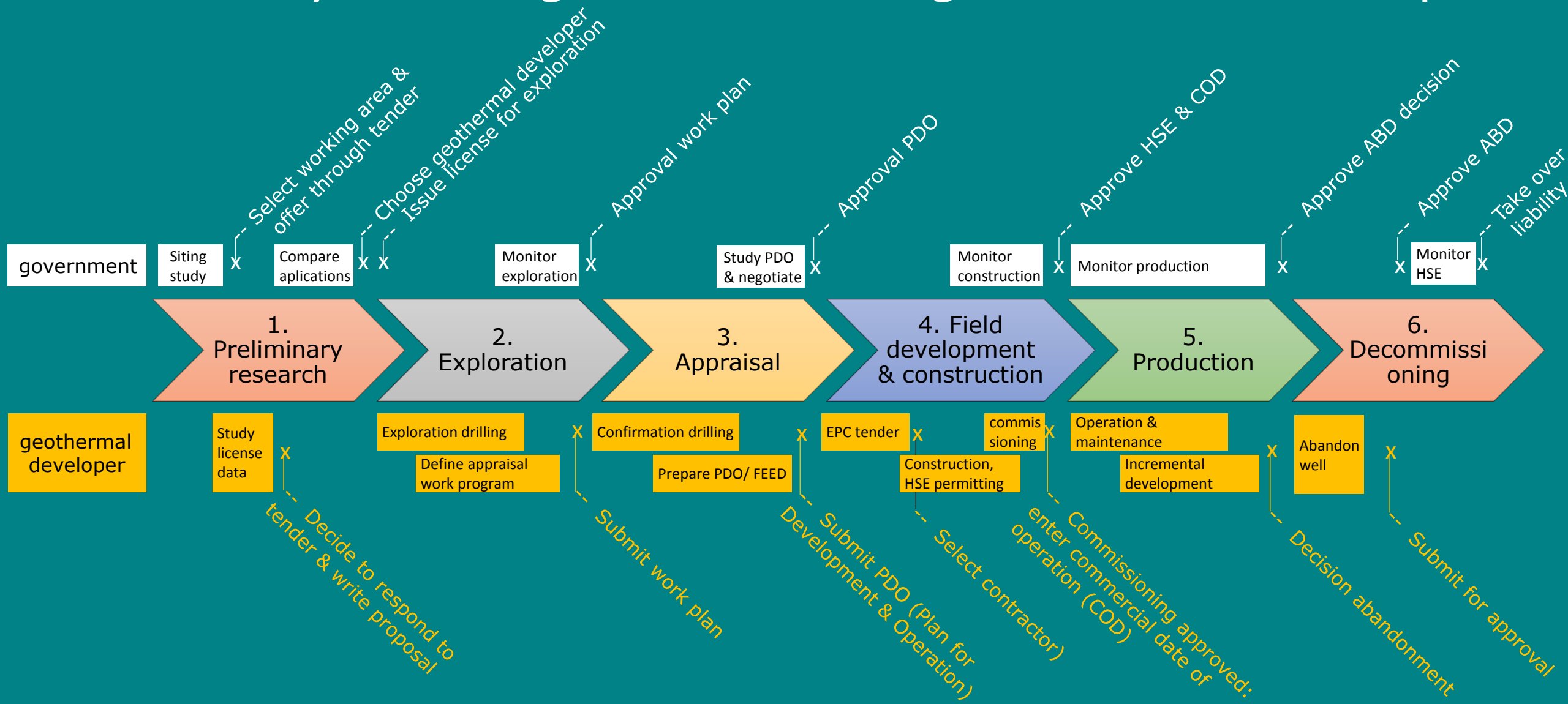
- Repurposing & recycling: Is it possible to use lower quality heat for other purposes? Are there components that can be sold/ used somewhere else?
- Decommissioning of the site (power plant & infrastructure)
- Government check: no hazard nor safety & environmental risks

After monitoring HSE for # years → liability is taken over by government

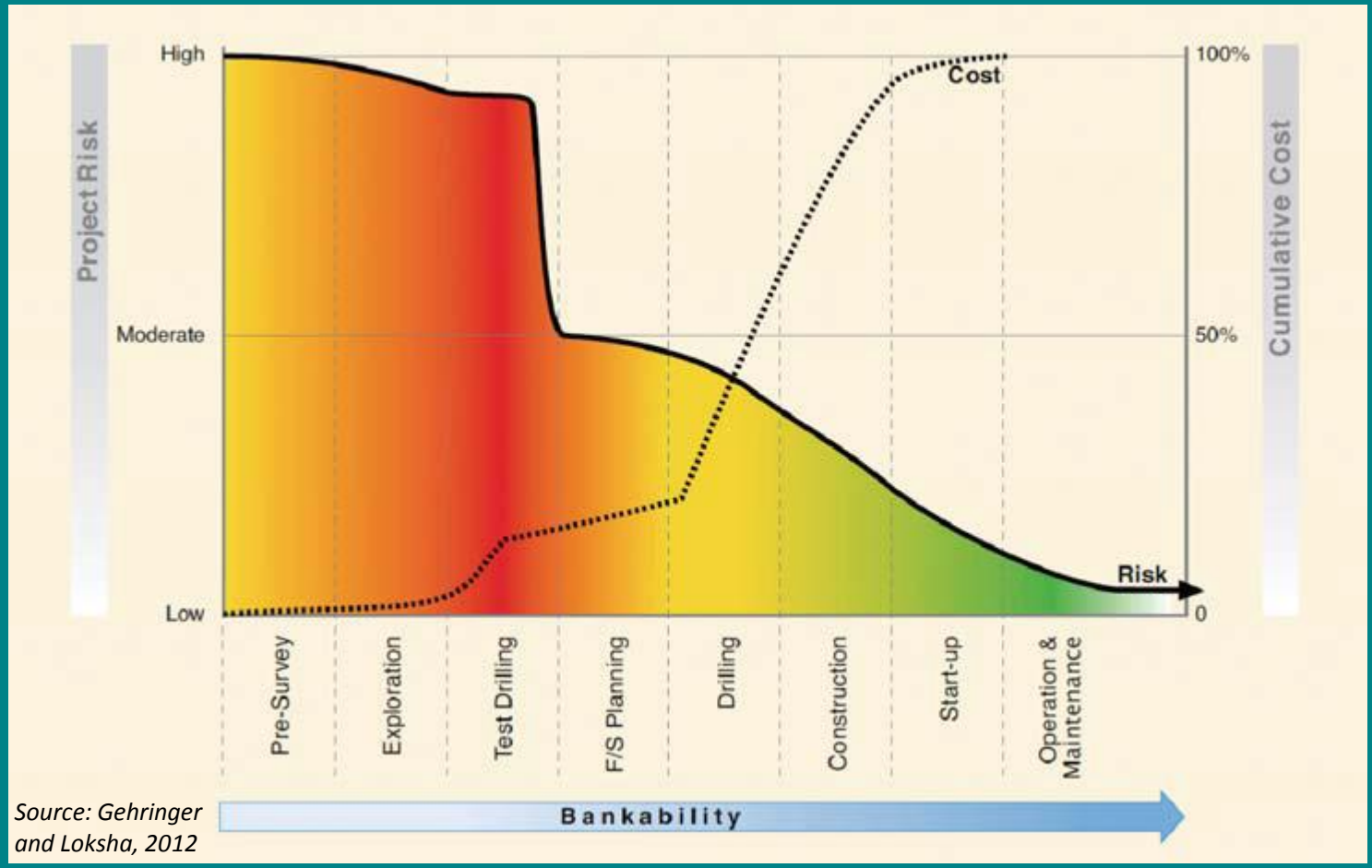
Goal: *Safe and clean site*

End of phase: *Approval decommissioning properly performed*

Summary – Role government & geothermal developer



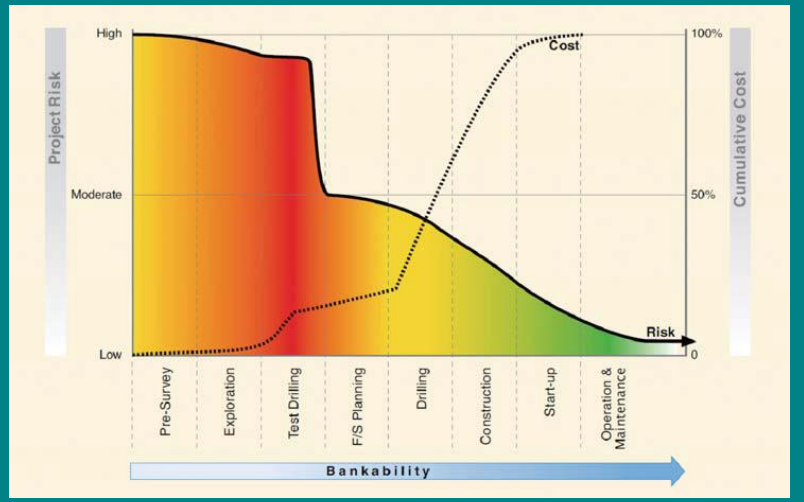
Project risks & costs geothermal energy plant



Source: Gehringer and Loksha, 2012

Balancing probability of success vs cost of failure

Risks



Geological risks	* Difficulty estimation resource capacity	
	* Changes in resource during operation (brine/ depletion/ permeability)	
Technical risks	* Oversizing plant → magnifies resource risk	
	* Excessive plant capacity can lead to unsustainable extraction rates (→ pressure drop/ reservoir depletion)	
Financing risks:	* Due to high upfront cost & long lead time	* Completion/ delay risk
Operational risks	* Well blockades/ collapsing	* HSE risks
Market risk:	* Off-take risk	* Price risk
Political risks:	* Regulatory risk	

Institutional capacity constraints, and information barriers.

Exercise geothermal energy plant

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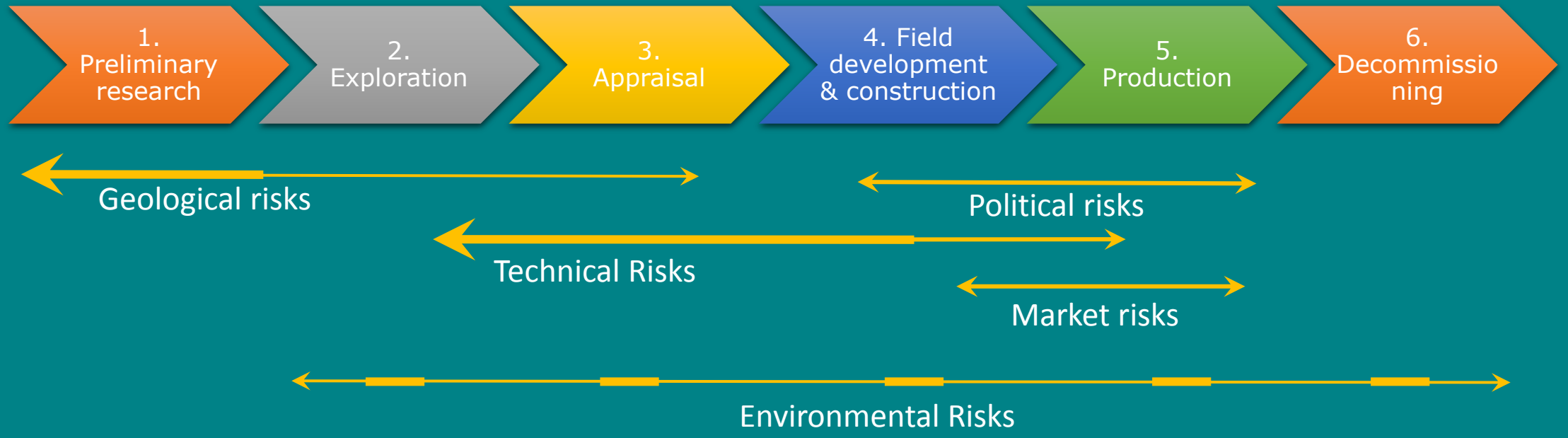

High investment & development costs

→ Resolve uncertainties to decrease the development risks

- collect information to make better predictions (less uncertainty)
- Make agreements/ contracts to take away uncertainty

→Balancing probability of success vs cost of failure (for example using decision tree)